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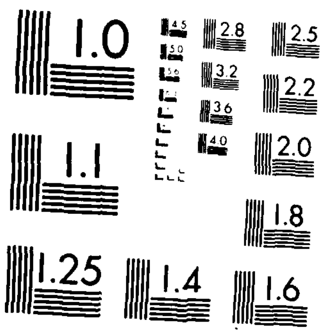


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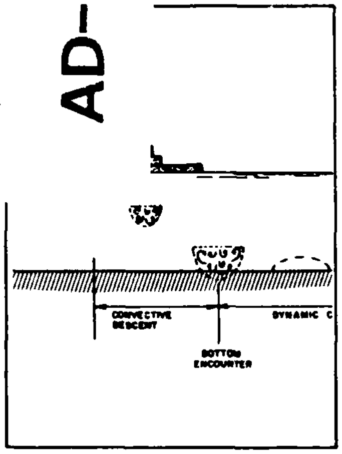


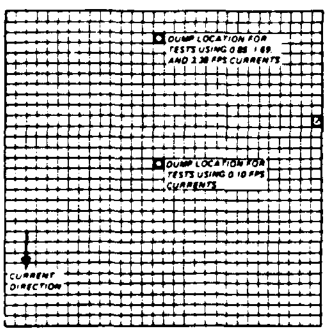


HYDRAULICS LABORATORY

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# PUGET SOUND GENERIC DREDGED MATERIAL DISPOSAL ALTERNATIVES

by

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DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)


Results from a series of numerical model runs predicting the short-term fate of dredged material disposed in open water are presented. These results cover a wide range of water depths and ambient currents. The range of conditions tested are intended to represent typical conditions for material to be disposed in Puget Sound. Because the maximum limits of material dispersion were of interest, dredged material with a high percentage of readily dispersed clay and silt was used in most of the disposal simulations. General conclusions are that for the typical maintenance material containing both sand and clay/silt, the disposed material will completely deposit within one hour for most conditions tested. The only tests which indicated that a portion of the material remained in suspension after an hour were those in 800 ft of water with currents of 1 knot or greater. In general, the deposition patterns were a function of both depth and ambient currents.


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# PREFACE

The estimation of short-term fate for the open-water disposal of dredged material in Puget Sound, documented in this report, was performed for the US Army Engineer District, Seattle.

The study was conducted in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) during the period from May 1985 to February 1986. This accomplishment was under the direction of Messrs. F. A. Herrmann, Jr., and R. A. Sager, Chief and Assistant Chief, respectively, of the HL; W. H. McAnally, Chief of the Estuaries Division; and M. B. Boyd, Chief of the Hydraulics Analysis Division.

The work was performed and the report prepared by Mr. M. J. Trawle and Dr. B. H. Johnson, HL, WES. This report was edited by Mrs. Gilda Shurden with Ms. Frances Williams, Information Products Division, WES, arranging and coordinating the final layout.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic metres |
| cubic yards | 0.7645549 | cubic metres |
| feet | 0.3048 | metres |
| feet per second | 0.3048 | metres per second |

PUGET SOUND GENERIC DREDGED MATERIAL DISPOSAL ALTERNATIVES

# PART I: INTRODUCTION

## Background

1. The US Army Engineer District, Seattle (NPS) is assessing Puget Sound dredged material disposal site alternatives for future dredged material derived from new work and maintenance dredging activities. The potential open water sites are located in water depths ranging from about 100 to 800 ft.* Currents range from still water (0.1 fps) to as great as 2 knots (3.38 fps). A key factor in the feasibility of disposal at each site is the ability to place the material within the defined boundaries of each site without significant dispersal beyond these limits.

## Objective

2. The objective of this investigation was to predict the short-term (less than one hour) fate of any dredged material from the Puget Sound area and barge dumped into the open water sites described in paragraph 1.

## Approach

3. The approach used to simulate the barge disposal of the dredged material was the numerical dump model DIFID (Disposal from Instantaneous Dump). The model predicted the deposition pattern of disposed material for each of the conditions tested as well as suspended sediment concentrations in the water column.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

# PART II: THE NUMERICAL MODEL, DIFID

## Description

4. DIFID was developed by Brandsma and Divoky (1976) for the US Army Engineer Waterways Experiment Station (WES) under the Dredged Material Research Program. Much of the basis for the model was provided by earlier model development by Koh and Chang (1973) for the barge disposal of wastes in the ocean. The work was conducted under funding by the Environmental Protection Agency (EPA) in Corvallis, Oreg. Modifications to the original model have been made by Johnson and Holliday (1978) and Johnson (in preparation).

5. The model requires that the dredged material be broken into various solid fractions with a settling velocity specified for each fraction. In many cases, a significant portion of the material falls as "clumps" that may have a settling velocity of perhaps 1 to 5 fps. This is especially true for the Puget Sound area, where much of the dredging is done by clamshell. This can also be true in the case of hydraulically dredged material if consolidation takes place in the hopper during transit to the disposal site. However, in order to evaluate the "worst case" and to determine the maximum extent of dispersal from a disposal operation, all model tests assumed that the dredged material was a slurry of uniform density.

6. The behavior of the disposed material is assumed to be separated into three phases: convective descent, during which the dump cloud or discharge jet falls under the influence of gravity; dynamic collapse, occurring when the descending cloud impacts the bottom; and long-term passive diffusion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation. Figure 1 illustrates these phases.

7. During convective descent, the dumped material cloud grows as a result of entrainment. The model assumes that none of the dumped material is lost to the water body during this phase. This assumption is supported by dredged material disposal monitoring in the lower part of Grays Harbor in 1982, in which no increase in suspended sediment concentrations were observed within the water column at a station located 1,000 meters from the

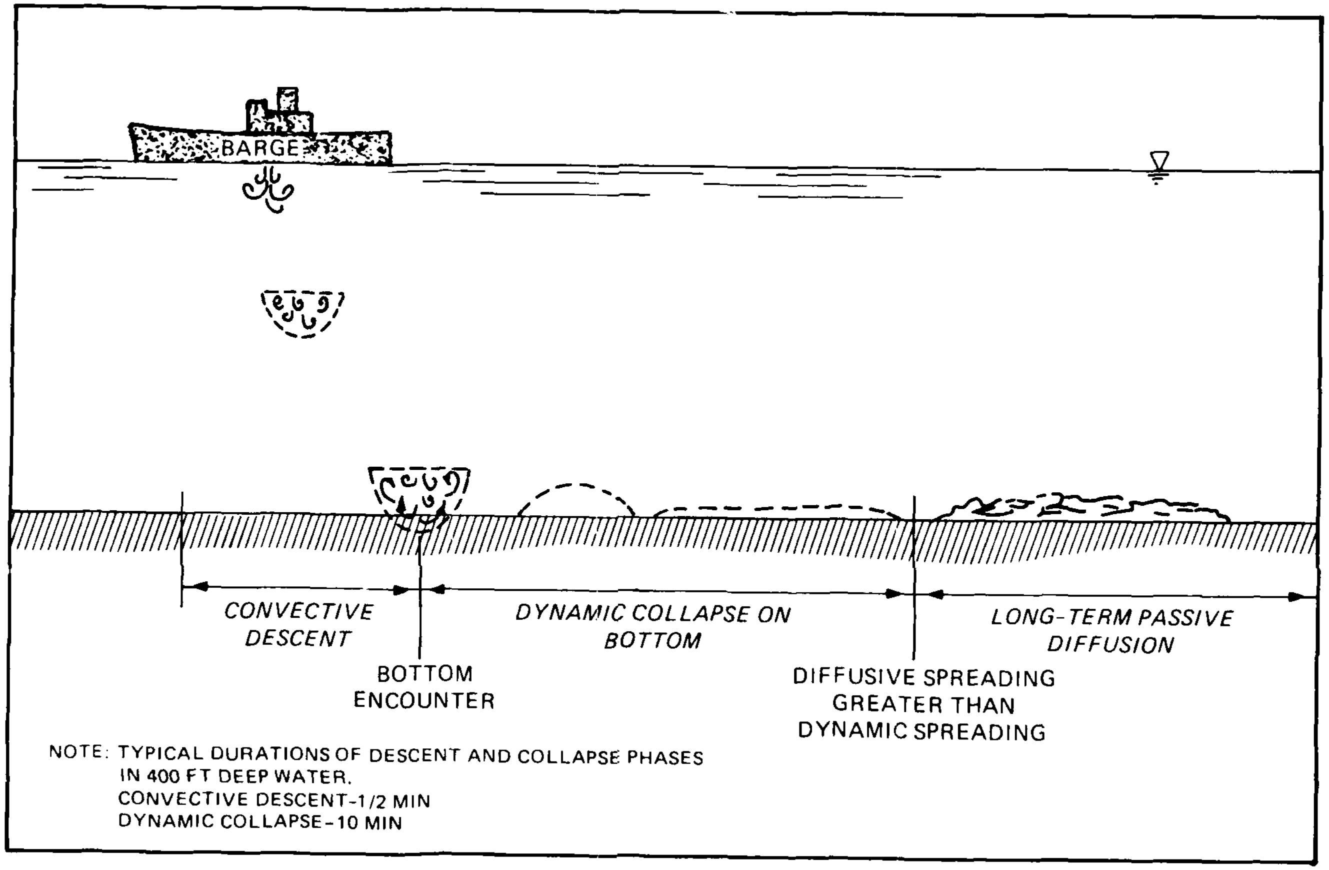


Figure 1. Illustration of idealized bottom encounter after instantaneous dump of dredged material

dump site.* The fact that nothing was detectable indicates that loss to the water column during descent was minimal. This is further supported by Gordon (1973, 1974) who estimated from observed data from a static bottom dump, that the turbidity cloud in the vicinity of the falling cloud contained less than 1 percent of the dumped material. Eventually, the material reaches the bottom or a neutrally buoyant position in the water column. The vertical motion is arrested and a dynamic spreading or collapse in the horizontal direction occurs. In 100 ft of water, the convective descent phase for typical maintenance material is completed in a few seconds after dumping. However, in 800 ft of water, the convective descent lasts about two minutes. The basic shape assumed for the collapsing cloud in the water column is an oblate spheroid. For the case of collapse on the bottom, the cloud takes the shape of a general ellipsoid and a frictional force between the bottom and the collapsing cloud is included. When the rate of horizontal spreading or vertical collapse in the dynamic collapse phase becomes less than an estimated rate of change due to turbulent diffusion, the collapse phase is terminated and the long-term transport diffusion begins. During collapse, solid particles can settle as a result of their fall velocity. As these particles leave the main body of material, they are stored in small clouds that are assumed to have a Gaussian distribution. The small clouds are then advected horizontally by the imposed current field. In addition, the clouds grow both horizontally and vertically as a result of turbulent diffusion. Since settling of the suspended solids occurs at each grid point, the amount of solid material deposited on the bottom and a corresponding thickness are determined. The model assumes that no subsequent erosion of material from the bottom occurs. A detailed description of the theoretical aspects of DIFID is given by Brandsma and Divoky (1976).

8. The deposition of material (solids volume) predicted by the model is converted to thickness of deposition by the use of an aggregate voids ratio. The equation used by the model to convert solids volume deposited to thickness of deposition (Brandsma and Divoky 1976) is

$$TH = \frac{1 + AVR}{AREA} \times VOL$$

---

* Personal communication between Dave Schuldt of the US Army Engineer District, Seattle, and Dr. James Phipps, Department of Geology-Oceanography, Grays Harbor College, 20 March 1986.

where

$TH$ = average grid cell thickness (ft)

$AVR$ = aggregate voids ratio

$AREA$ = grid cell size ($400 \times 400$ ft$^2$)

$VOL$ = solids volume (cu ft)

9. If the material being dumped is cohesive, and particle aggregation can be expected to occur during the disposal operation, the model has the capability to use aggregate, rather than particle, settling velocities. The aggregate settling velocity for the clay/silt (cohesive) fraction is determined in the model by the following set of equations (Johnson and Holliday 1978).

$$V_s = \begin{cases} 0.0017 \text{ if } C \leq 25 \text{ mg/l} \\ 0.0000233\, C^{4/3} \text{ if } 25 \leq C \leq 300 \text{ mg/l} \\ 0.047 \text{ if } C > 300 \text{ mg/l} \end{cases}$$

## Required Input Data

10. The required input data to DIFID can be grouped into (a) a description of the ambient environment at the disposal site, (b) characterization of the dredged material, (c) data describing the disposal operation, and (d) model coefficients.

11. The first task is that of constructing a horizontal grid over the disposal site. The model grid used in this study is shown in Figure 2. The ambient conditions imposed on the grid model for these tests were represented by a constant water depth and density and a depth-averaged time invariant current velocity. The model has the capability to handle a time varying depth-averaged flow field or a time varying three-dimensional flow field, but neither of these options was used. In all cases, a single water density profile at the deepest point on the grid must be prescribed.

12. Although the model has the capability to handle dredged material composed of as many as 12 fractions, the dredged material for these tests was characterized by two solid fractions. For each solid fraction, its concentration by volume, density, fall velocity, voids ratio, and an indicator as to whether or not the fraction is cohesive must be specified. In addition, the bulk density and aggregate voids ratio of the material must be prescribed. The

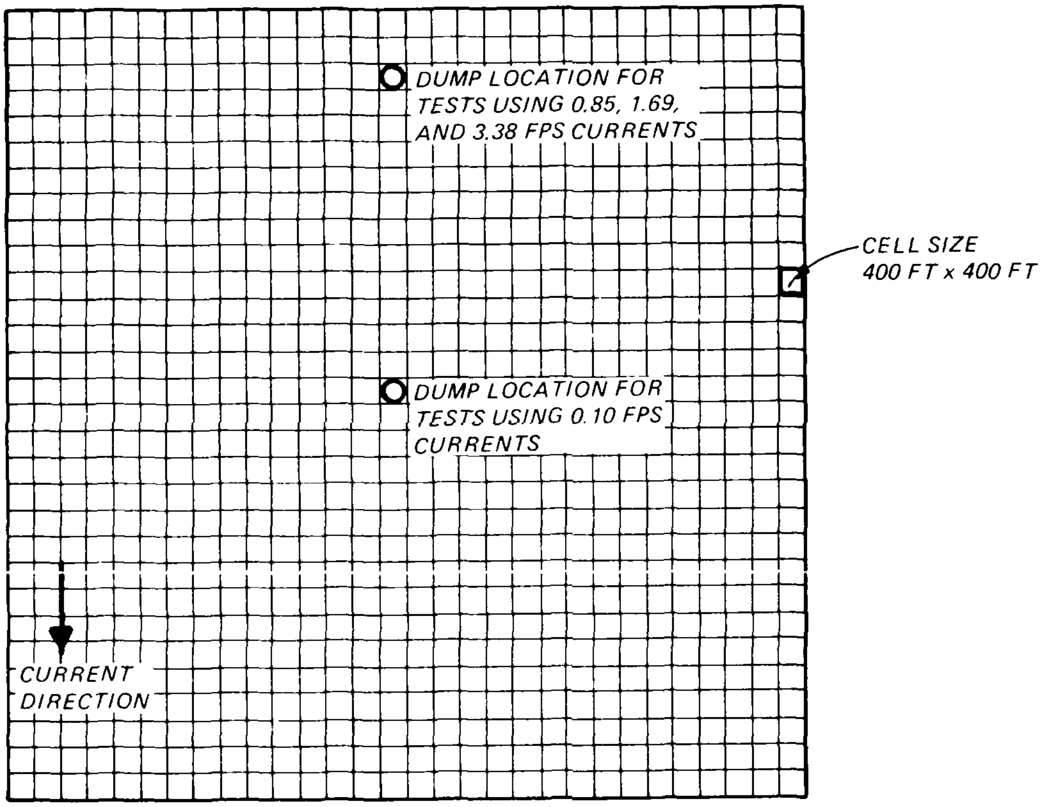


Figure 2. Puget Sound model grid

bulk density is the density of the slurry in the barge. As discussed in paragraph 8, the aggregate voids ratio is actually a bulking factor used to convert the mass of deposited material to a thickness of deposition.

13. Disposal operations data required include the position of the barge on the horizontal grid, the volume of material dumped, and the loaded and unloaded draft of the disposal vessel.

14. There are 14 model coefficients in DIFID. These required coefficients include entrainment, drag, and turbulent diffusion. Default values that reflect the model developer's judgment are contained in the code. Computer experimentation, such as that presented by Johnson and Holliday (1978), has shown that results appear to be fairly insensitive to many of the coefficients. The most important are drag coefficients in the convective descent and collapse phases as well as those coefficients governing the entrainment of ambient water into the dredged material cloud. The values selected for the convective descent entrainment and drag coefficients in this study were based upon experimental work done by Bowers and Goldenblatt (1978).

15. Model limitations should be considered in the interpretation and use of model results. These limitations include: (a) limited knowledge of appropriate values for the various model coefficients; (b) imprecise specification of settling velocities for the dumped material; (c) representation of real disposal operations in an idealized fashion, e.g., an instantaneous dump in this case; and (d) limited model verification with no field observations at the depths to which the model is being applied in some tests.

16. Discussion of a model application using field observations at a disposal site located in Elliott Bay where the average water depth is approximately 200 ft is presented below. The main reason that field tests have not been conducted in water deeper than 200 ft is expense. To observe the bottom behavior of a collapsing cloud in 800 or even 400 ft of water depth would be extremely costly. Until such data are available, the assumption is that if the model behaves properly in 200 ft of water depth, the extrapolation of model applications to greater depths is valid.

## Model Verification - Elliott Bay, Washington

17. During February 1976, personnel from Yale University (Bokuniewicz et al. 1978) monitored a barge disposal operation at the Duwamish disposal

site in Elliott Bay near Seattle, Wash. The dump was made from a 530-cu-yd stationary barge. The material possessed an average bulk density of 1.50 g/cc, with the solid material composed of 55 percent fine material and 45 percent sand. Although the data collected for comparison with computed results from DIFID were very limited, the model application and comparison to field data in an area physically near the present disposal site of interest will increase confidence in the model's predictive capability in these areas.

18. When attempting to apply any of the dredged material models (DIFID for instantaneous barge dumps, DIFCD for continuous discharges, or DIFHD for hopper dredges) to real disposal operations, a basic problem is that of determining how to apply these models so that an actual operation can be represented by the idealized methods of disposal considered in the models. For example, there are no dredged material disposals in which all of the material leaves the disposal vessel instantaneously. However, for the case of a barge dump such as that monitored at the Duwamish disposal site in Elliott Bay, all of the material left the barge fairly quickly. Also, the water was of such depth that a dump did resemble a hemispherical cloud falling through the water column by the time the bottom was encountered. Thus, the instantaneous dump model, DIFID, is the appropriate model for barge dumps at the Duwamish disposal site in Elliott Bay.

19. The water depth at the Duwamish disposal site was 197 ft with the ambient current near the bottom measuring about 0.3 fps.

20. During the Duwamish disposal site dump operation, a time of 25 sec was observed for the leading edge of the disposal cloud to strike the bay bottom. The model, DIFID, computed a descent time of 23 sec, thus comparing closely with the observed descent time. The speed of the front of the bottom surge at 160 ft from the point of the dump was measured to be 20 cm/sec. The speed of the bottom surge computed by the model at 160 ft from the point of dump was 22 cm/sec, again comparing well with the field observation. During field monitoring, suspended solids concentrations were measured at 3 ft above the bottom at a location 300 ft downstream of the dump point. Within 60 sec following the dump, the measured suspended sediment concentration was 64 mg/ℓ. The corresponding concentration computed from the dump model was 75 mg/ℓ, again demonstrating reasonable behavior.

21. Proper material characterization is extremely important in obtaining realistic model predictions. The results discussed above were

obtained by assuming that 30 percent of the fine material behaved as consolidated clumps, 65 percent of the fine material behaved as a cohesive flocculating sediment, and the remaining 5 percent of the fine material retained individual particle characteristics.

22. In summary, with proper material characterization and selection of values for the more sensitive model coefficients, the model, DIFID yielded results which compared favorably with the field observations made at the Duwamish disposal site in Elliott Bay, Wash.

## PART III: TEST PROGRAM AND RESULTS

### Test Conditions

23. The water depth, ambient current, material dumped, and barge bulk density used in each of the tests are as shown in Table 1. The remainder of the required model input for each series is shown in Table 2.

Grid size

24. The model grid used for all tests is shown in Figure 2, which represents an area of 12,000 by 12,000 ft. Each grid cell represented an area of 400 by 400 ft.

Dump size

25. To be representative of a typical barge operating in the Puget Sound area, the dump size used in all tests was 1,500 cu yd.

Duration of simulations

26. The duration of each test was intended to be 3,600 sec (1 hr) after the barge dump. However, in the tests with the 3.38-fps ambient current velocity, dumped material remaining in suspension reached the model boundary within one hour, which automatically ended the test.

Dump spot

27. The locations of the dumps for each test are shown in Figure 2.

Model coefficients

28. The model coefficients used in this study, as well as the default values, are given in Table 3. The default values for coefficients were established during the original model development.

Material type

29. The dumping of two types of material was modeled in these tests. The primary material tested consisted of 25 percent fine sand and 75 percent clay/silt. The clay/silt fraction was modeled as both cohesive and noncohesive materials. The second material consisted of 50 percent fine sand and 50 percent medium sand with no clay/silt.

### Test Results

30. Results from the model tests are shown as deposition patterns in Plates 1 to 21. These deposition patterns demonstrate the predicted extent

and thickness of material deposited from a single 1,500-cu-yd disposal operation. For the tests (Plates 13-19) in which all the material had not been deposited after 60 min, the patterns represent the deposition extent and thickness for that portion of the dumped material which had deposited after 60 min.

Tests 1-15

31. The material simulated in Tests 1-15 represents a typical maintenance material in the Puget Sound area, consisting of 25 percent fine sand and 75 percent clay/silt. In these tests, the clay/silt fraction was allowed to aggregate, resulting in aggregate settling rates which are significantly greater than the particle settling velocity. For fine-grained silts and clays, it is reasonable to assume that particle aggregation will occur as the material settles, resulting in accelerated settling velocities.

32. For Tests 1-12, in depths of water ranging from 100 to 600 ft, all of the dumped material deposited within the 60-min simulation period (Plates 1-12). For Test 13, in 800 ft of water and with an ambient current speed of 0.1 fps, almost all the material deposited within one hour (Plate 13). However for Test 14, in 800 ft of water and a current speed of 1.69 fps, a portion of the clay/silt fraction of dumped material was still in suspension after one hour (Plate 14). For Test 15, in 800 ft of water and with a current speed of 3.38 fps, the duration of the test was limited to 30 min, at which time a portion of the clay/silt fraction remained in suspension (Plate 15). The 30-min limit was imposed because at that time sediment had reached the model boundary. A longer simulation would have required extending the grid.

Tests 16-18

33. Tests 16-18 were identical to Tests 7-9 except that the clay/silt fraction was not allowed to aggregate. Therefore, only particle settling velocities were used in the model computations. Comparison of Tests 7-9 with Tests 16-18 demonstrates that the deposition pattern is much more dispersed if aggregate settling is not considered. However, as stated earlier, the results which include aggregate settling for the cohesive fraction of material should be more realistic than results which do not.

Test 19

34. Test 19 is identical to Test 18 except that the barge bulk density was increased from 1.35 to 1.48 g/cc. As can be seen by comparison of

Plates 18 and 19, the impact of the increased bulk density with regard to the extent of the deposition pattern was negligible under these conditions.

Tests 20 and 21

35. Test 20 used a material which consisted only of fine and medium sands dumped in water 800 ft deep with an ambient current of 1.69 fps (Plate 20). Test 21 (Plate 21) was identical to Test 20 except that the water depth was only 100 ft. As can be seen, the resulting deposition patterns for these two tests are more compact than for the equivalent tests (Tests 2 and 14) using a large clay/silt fraction.

## PART IV: SUMMARY AND CONCLUSIONS

### Summary

36. A numerical model for predicting the short-term fate of dredged material dumped into open water has been applied over a range of disposal site conditions representative of those encountered in Puget Sound. The water depths ranged from 100 to 800 ft with current speeds ranging from essentially zero to over 3 fps. Two different disposal materials were tested; the first consisting of 25 percent fine sand and 75 percent clay/silt; and the second 50 percent fine sand and 50 percent medium sand. Tests were conducted using bulk densities of 1.35 and 1.48 g/cc. The clay/silt fraction of material was tested as both cohesive and noncohesive. Model coefficients were generally selected to be the values determined during the model development (default values). However, coefficients pertaining to the convective descent of the material through the water column were determined from tank test data collected by JBF Scientific (Bowers and Goldenblatt 1978).

### Conclusions

37. The results presented should be viewed in a qualitative sense since field data were not available for model adjustment. In addition, various assumptions in the model development should be considered in an analysis of the model results. These include:

- a. The model treats each of the sediment fractions separately. In an actual settling process there would be interaction of the various solid fractions. This interaction would probably result in more rapid settling than depicted by the model.
- b. The ability of the model to accurately portray water column concentrations decreases as the percent of material in suspension decreases and as the time into the simulation increases. At the point where the percent suspended becomes less than 5 percent and the time exceeds perhaps 1,800 sec, other uncertainties become extremely important factors. Such inconsistencies include how much material dissociates from the clouds in the descent phase and the influence of turbulent diffusion in the vertical.
- c. In an actual disposal operation, the material leaving the barge may differ considerably from that being modeled. Factors such as the relative quantities of the various fractions of material, water content, the percent of clumps, and time for the

material to leave the barge, all significantly affect the spread of material on the bottom. The conditions assumed for this study represent a "worst case" or "maximum dispersal" situation.

38. Results from the model tests are presented in such a manner as to show the amount and physical limits of dredged material deposited on the bottom within one hour after the dump occurred. In the tests for which the clay/silt was treated as cohesive (Tests 1 to 15), all of the material was deposited within one hour after dumping except for Tests 13, 14, and 15. In 800 ft of water along with a current speed of 0.1 fps (Test 13), only a small fraction of the dumped material remained in suspension after one hour. In 800 ft of water along with a current speed of 1.69 fps (Test 14), a portion of the dumped material was still in suspension after one hour. In 800 ft of water along with a current speed of 3.38 fps (Test 15), the test duration was limited to 30 min, at which time a portion of the dumped material remained in suspension. Tests 16 to 18 demonstrated that if the cohesive nature of the dumped material is not considered, the deposition pattern is significantly more dispersed than for the equivalent tests with the cohesive option invoked. Test 19 demonstrated that the impact of increased bulk density (from 1.35 to 1.48 g/cc) on the overall deposition pattern was negligible for the condition tested. Finally, Tests 20 and 21 showed that the dumping of a sandy material containing no clay/silt resulted in deposition patterns that were more compact than the patterns for material containing a large clay/silt fraction, given equivalent recurring water body conditions.

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Table 1

Test Conditions

| Test No. | Water Depth (ft) | Current (fps) | Material % Fine Sand | Material % Clay/Silt | Bulk Density (g/cc) | Aggregated Settling Velocities for Clay/Silt Fraction |
|---|---|---|---|---|---|---|
| 1 | 100 | 0.10 | 25 | 75 | 1.35 | Yes |
| 2 | 100 | 1.69 | 25 | 75 | 1.35 | Yes |
| 3 | 100 | 3.38 | 25 | 75 | 1.35 | Yes |
| 4 | 200 | 0.10 | 25 | 75 | 1.35 | Yes |
| 5 | 200 | 0.85 | 25 | 75 | 1.35 | Yes |
| 6 | 200 | 1.69 | 25 | 75 | 1.35 | Yes |
| 7 | 400 | 0.10 | 25 | 75 | 1.35 | Yes |
| 8 | 400 | 0.85 | 25 | 75 | 1.35 | Yes |
| 9 | 400 | 1.69 | 25 | 75 | 1.35 | Yes |
| 10 | 600 | 0.10 | 25 | 75 | 1.35 | Yes |
| 11 | 600 | 0.85 | 25 | 75 | 1.35 | Yes |
| 12 | 600 | 1.69 | 25 | 75 | 1.35 | Yes |
| 13 | 800 | 0.10 | 25 | 75 | 1.35 | Yes |
| 14 | 800 | 1.69 | 25 | 75 | 1.35 | Yes |
| 15 | 800 | 3.38 | 25 | 75 | 1.35 | Yes |
| 16 | 400 | 0.10 | 25 | 75 | 1.35 | No |
| 17 | 400 | 0.85 | 25 | 75 | 1.35 | No |
| 18 | 400 | 1.69 | 25 | 75 | 1.35 | No |
| 19 | 400 | 1.69 | 25 | 75 | 1.48 | No |
| 20 | 800 | 1.69 | 50 | 50 | 1.48 | Not Applicable |
| 21 | 100 | 1.69 | 50 | 50 | 1.48 | Not Applicable |

Table 2

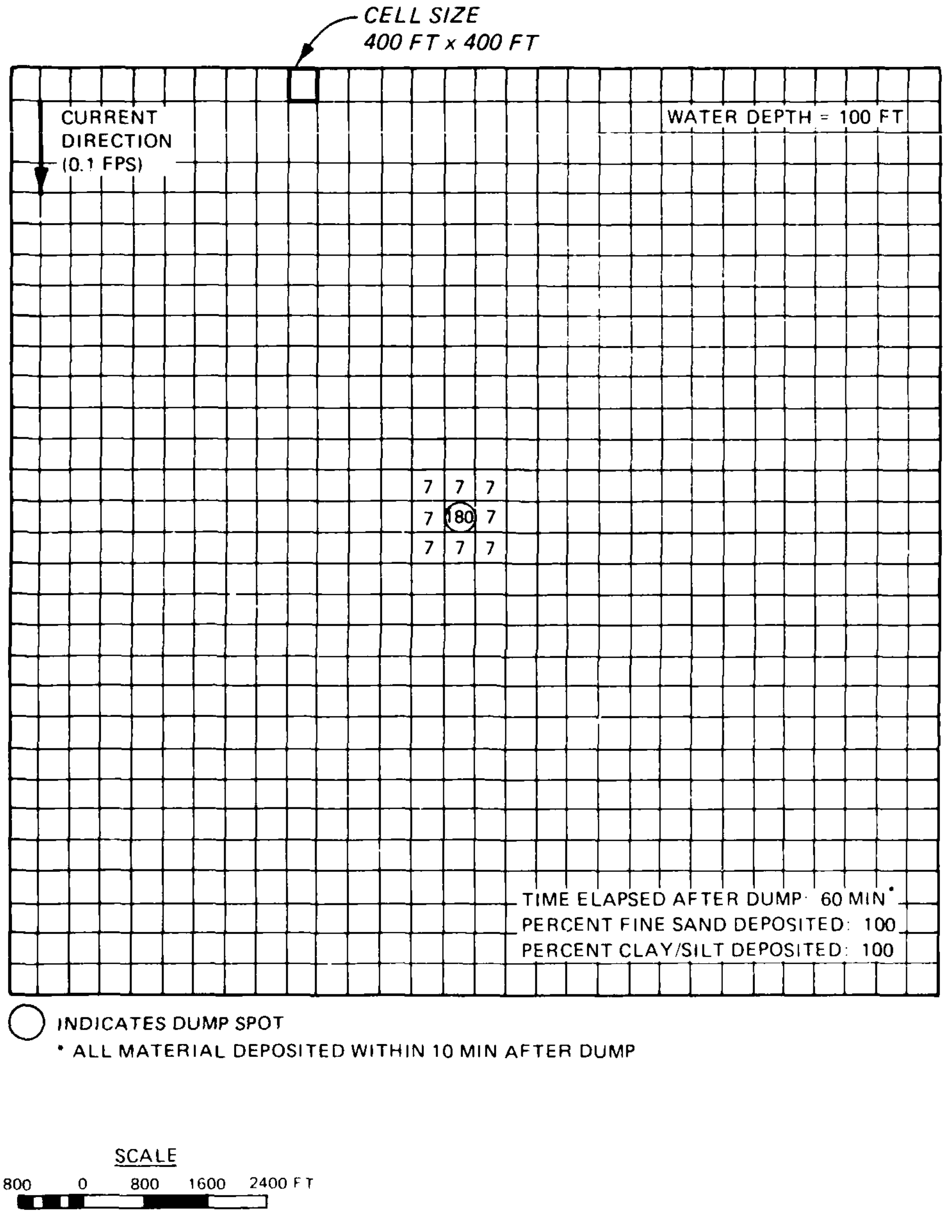
Model Input Information

| | Tests 1-15 | Tests 16-18 | Test 19 | Tests 20-21 |
|---|---|---|---|---|
| Medium sand concentration by volume (cu ft/cu ft) | -- | -- | -- | 0.15 |
| Fine sand concentration by volume (cu ft/cu ft) | 0.05 | 0.05 | 0.07 | 0.15 |
| Clay/silt concentration by volume (cu ft/cu ft) | 0.16 | 0.16 | 0.22 | -- |
| Sand density (g/cc) | 2.60 | 2.60 | 2.60 | 2.60 |
| Clay/silt density (g/cc) | 2.60 | 2.60 | 2.60 | -- |
| Fluid density (g/cc) | 1.018 | 1.018 | 1.018 | 1.018 |
| Medium sand fall velocity (fps) | -- | -- | -- | 0.03 |
| Fine sand fall velocity (fps) | 0.02 | 0.02 | 0.02 | 0.02 |
| Clay/silt fall velocity (fps) | 0.0013 | 0.0013 | 0.0013 | -- |
| Dredged material bulk density (g/cc) | 1.35 | 1.35 | 1.48 | 1.48 |
| Aggregate voids ratio | 4.50 | 4.50 | 4.50 | 4.50 |
| Cohesive aggregate option for clay/silt fraction | ON | OFF | OFF | Not Applicable |

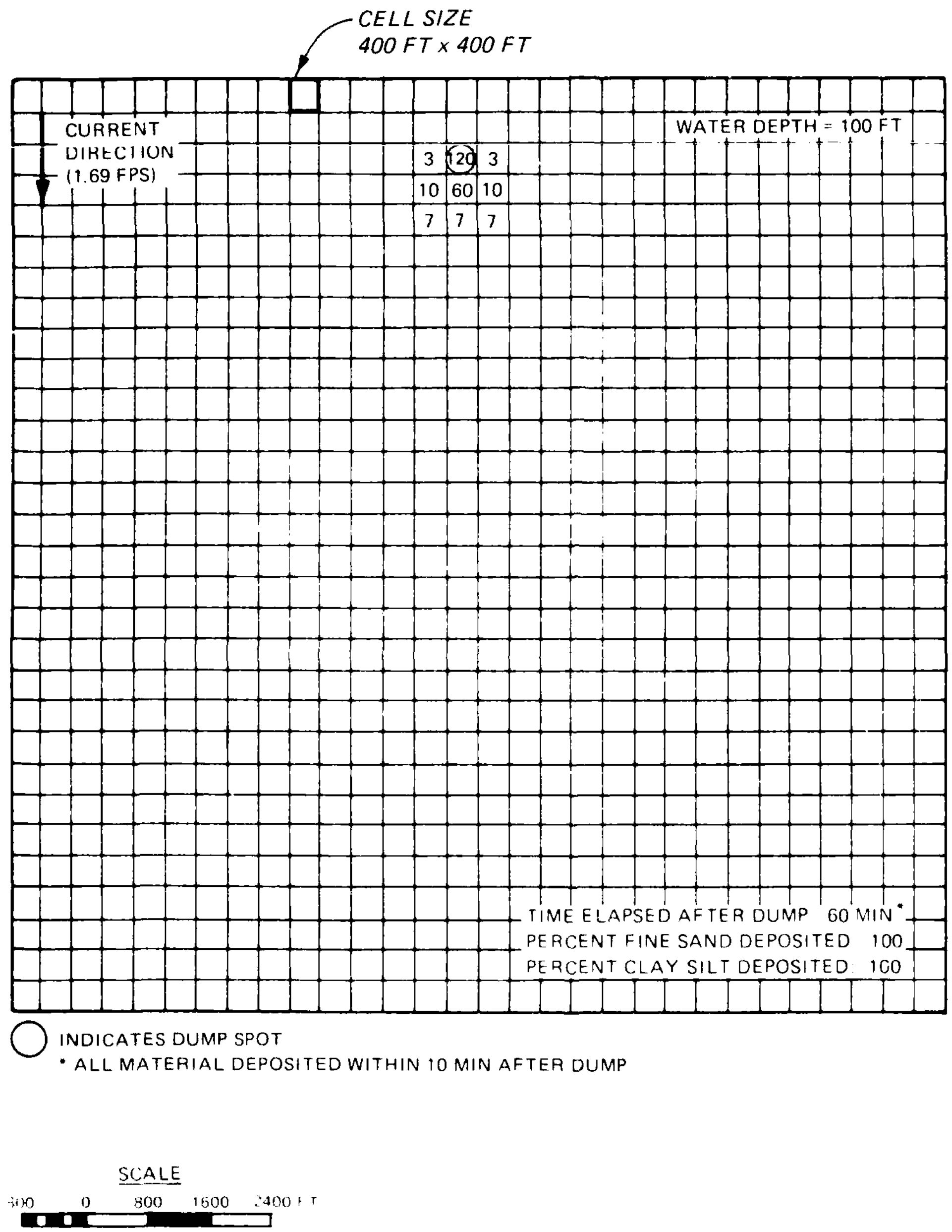
Table 3

Values for Model Coefficients

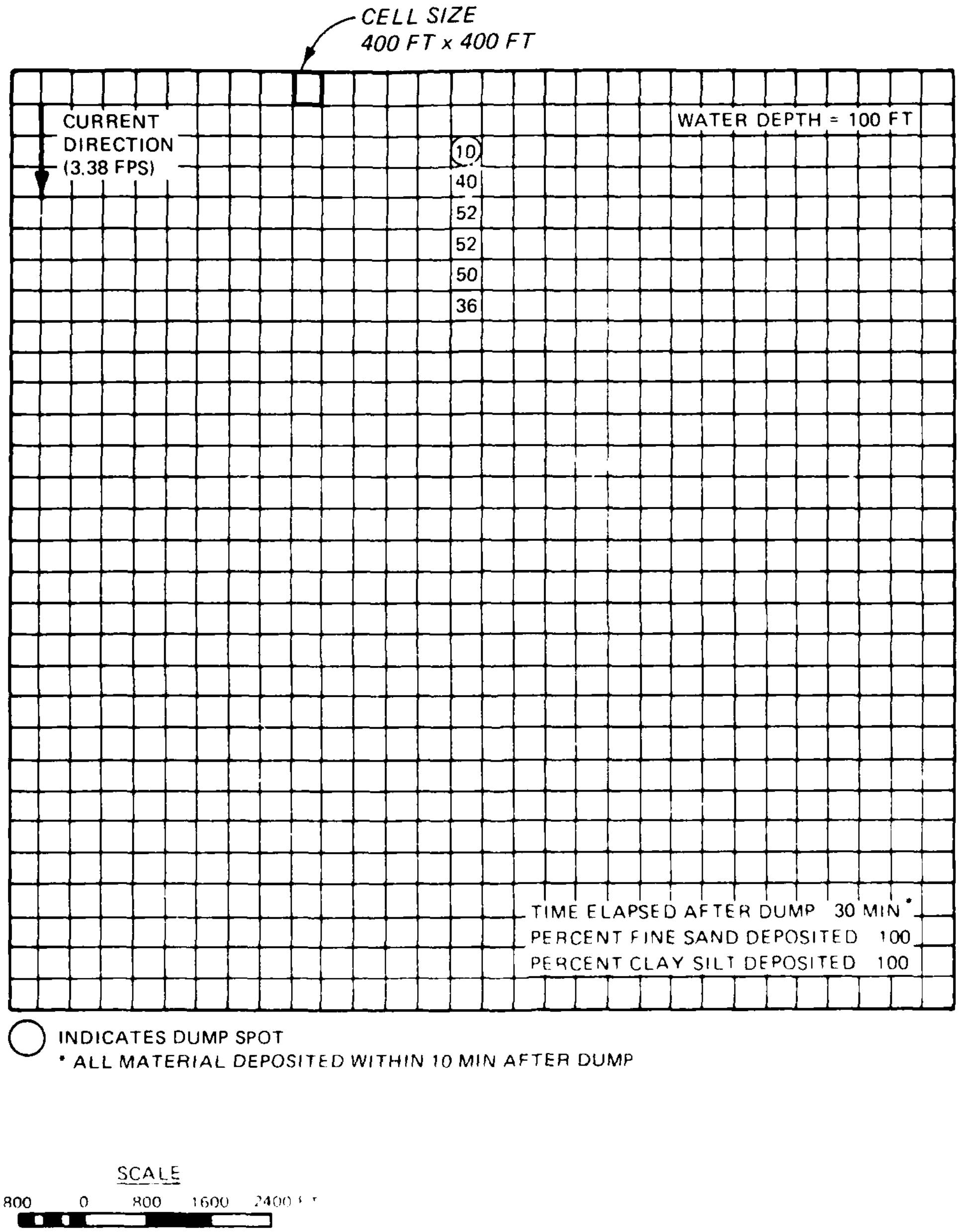
| Coefficient | Description | Default Value | Value Used |
|---|---|---|---|
| $\sigma_o$ | Convective descent entrainment | 0.235 | 0.275 |
| $\beta$ | Settling coefficient | 0.0 | 0.0 |
| CM | Apparent mass coefficient | 1.0 | 0.40 |
| CD | Drag coefficient of sphere | 0.50 | 0.21 |
| $\phi$ | Relates cloud density gradient to ambient density gradient | 0.25 | 0.25 |
| CDRAG | Drag coefficient of oblate spheroid | 1.0 | 0.50 |
| CFRIC | Skin friction of oblate spheroid | 0.01 | 0.01 |
| CD3 | Drag coefficient of ellipsoidal wedge | 0.10 | 0.10 |
| $\sigma_c$ | Collapse entrainment coefficient | 0.001 | 0.02 |
| FRICTN | Bottom friction coefficient | 0.01 | 0.01 |
| FI | Modification factor in bottom friction force | 0.10 | 0.10 |
| ALAMDA | Dissipation parameter | 0.005 | 0.005 |
| AKYO | Maximum value of vertical diffusion coefficient | 0.05 | 0.005 |



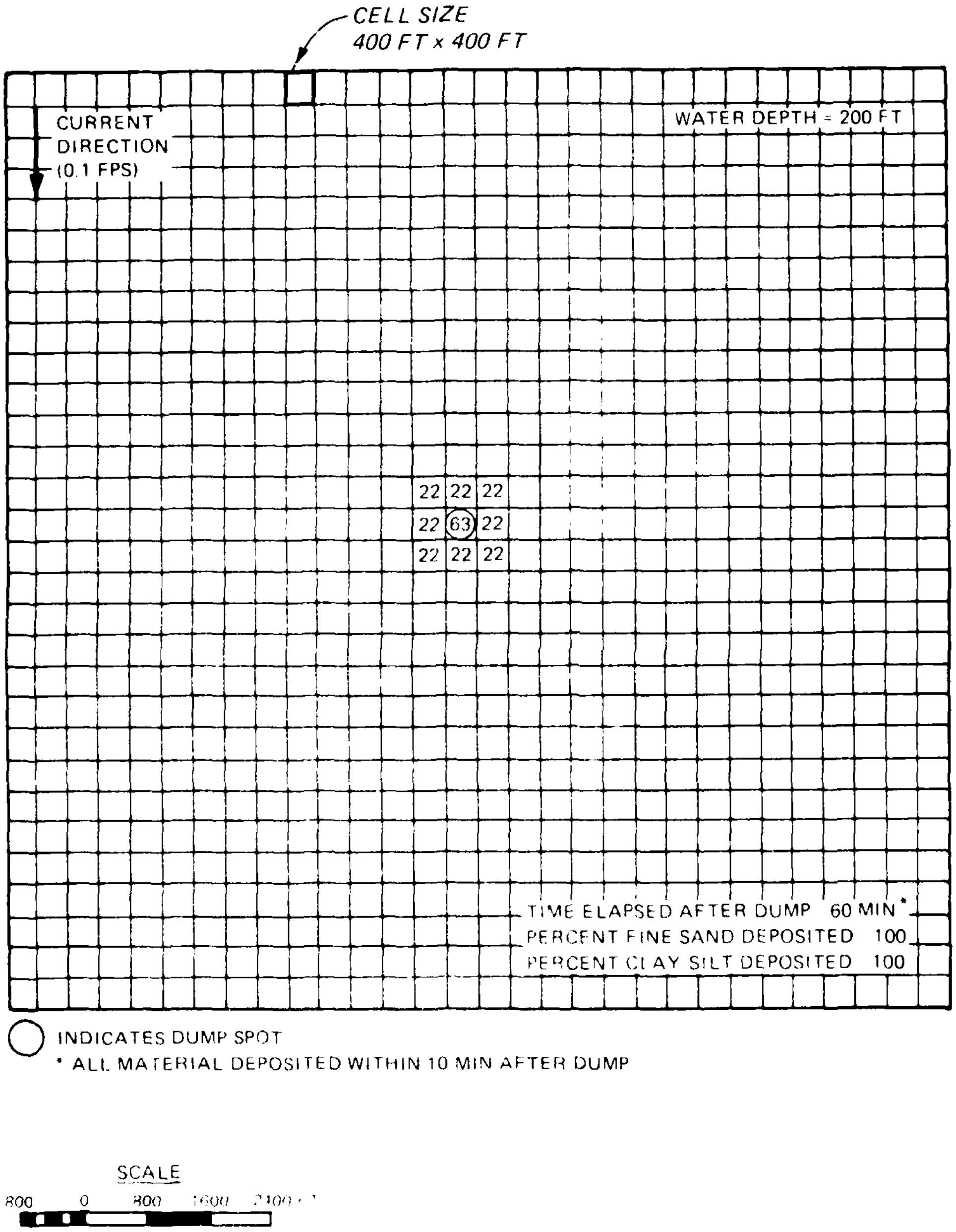

DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 1




DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 2

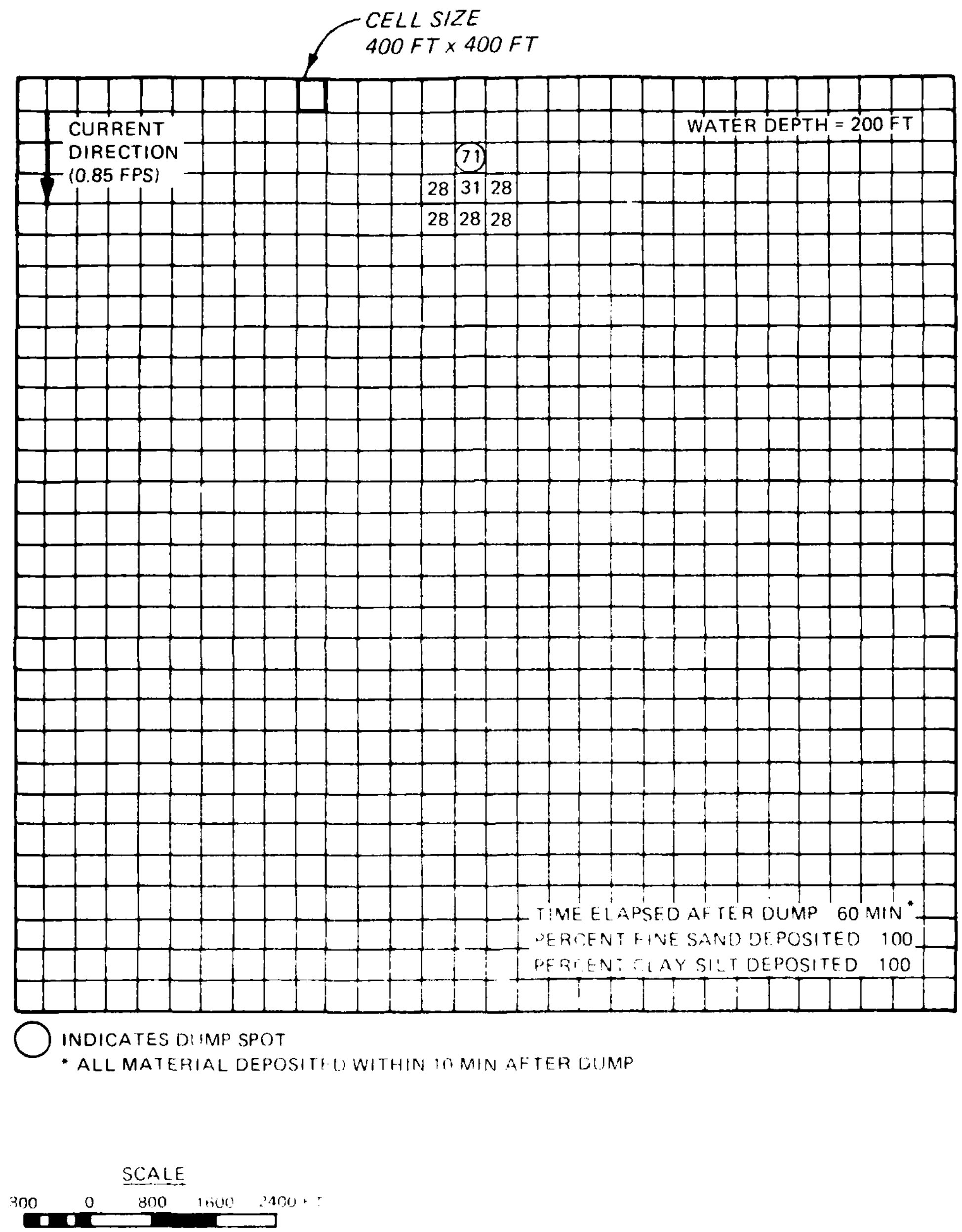



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 3



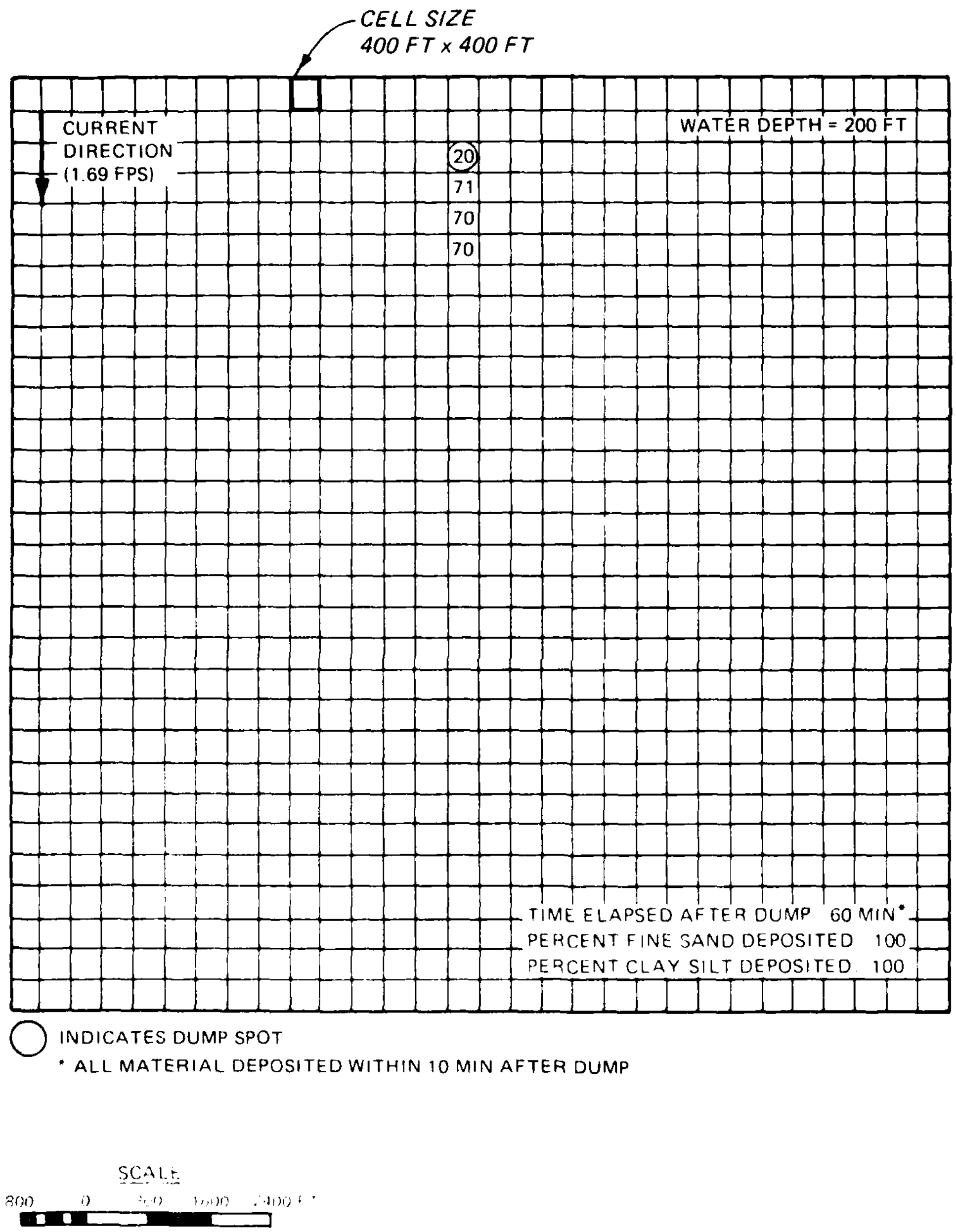

DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 4

PLATE 4



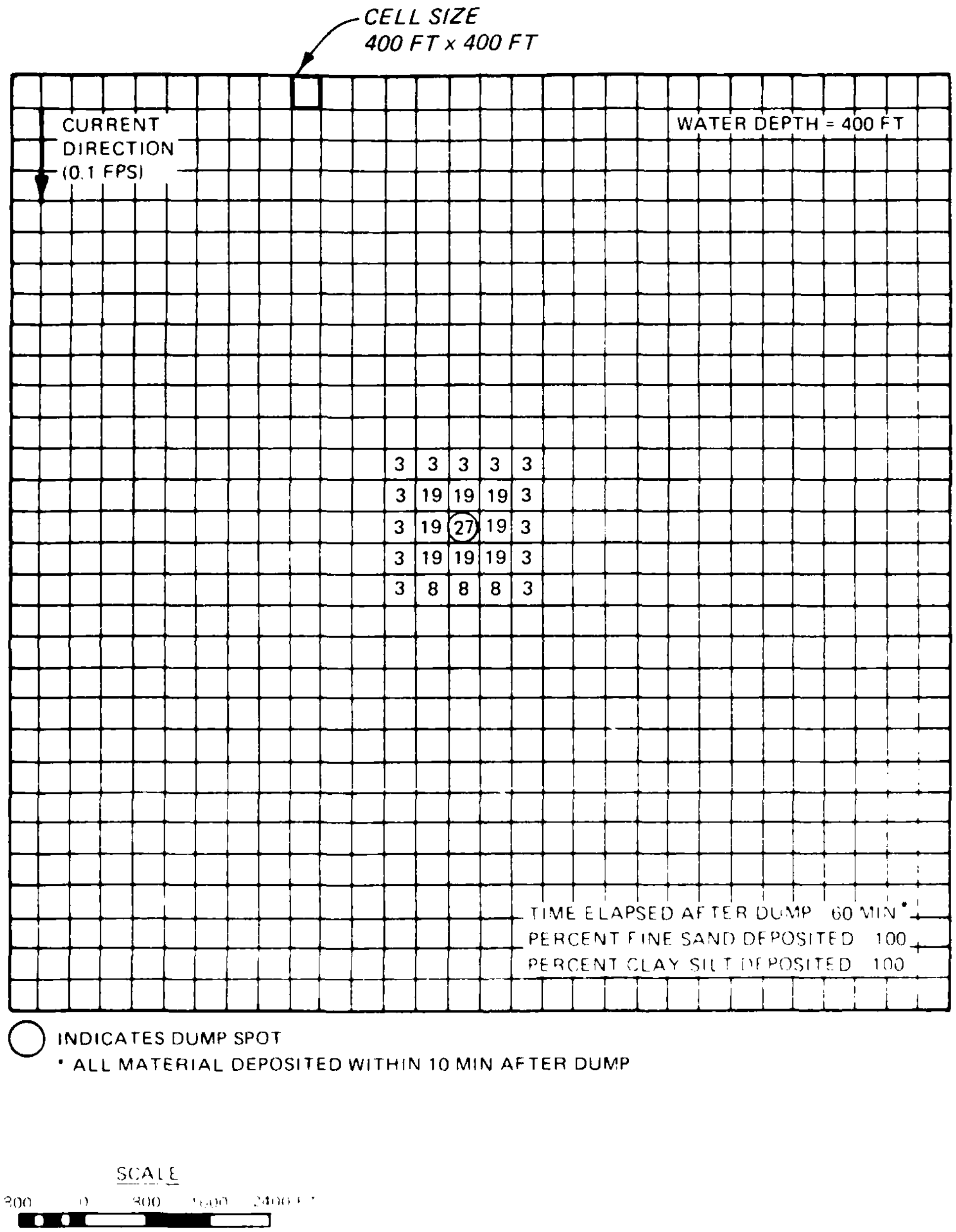

DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 5

PLATE 5

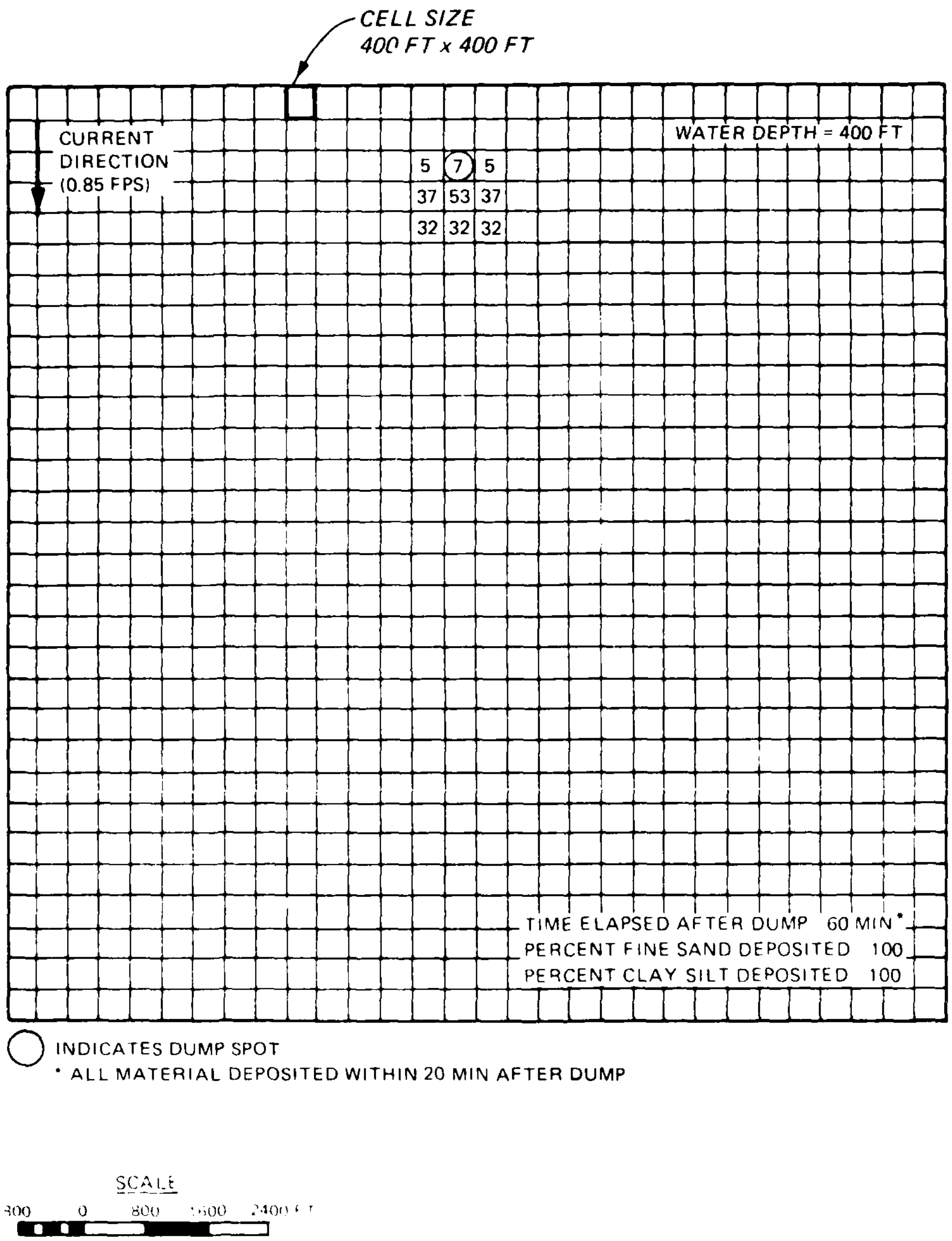



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 6

PLATE 6

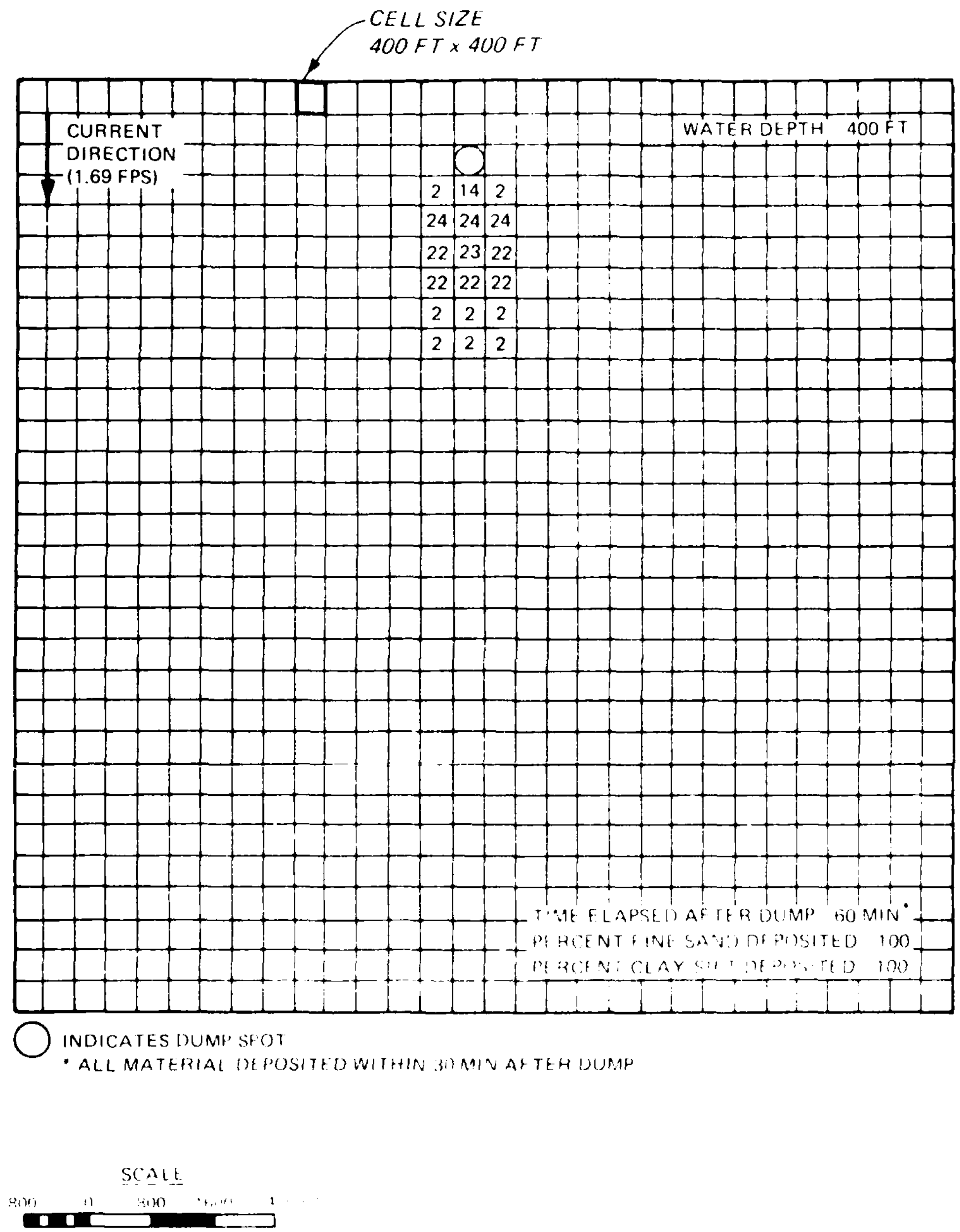



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 7

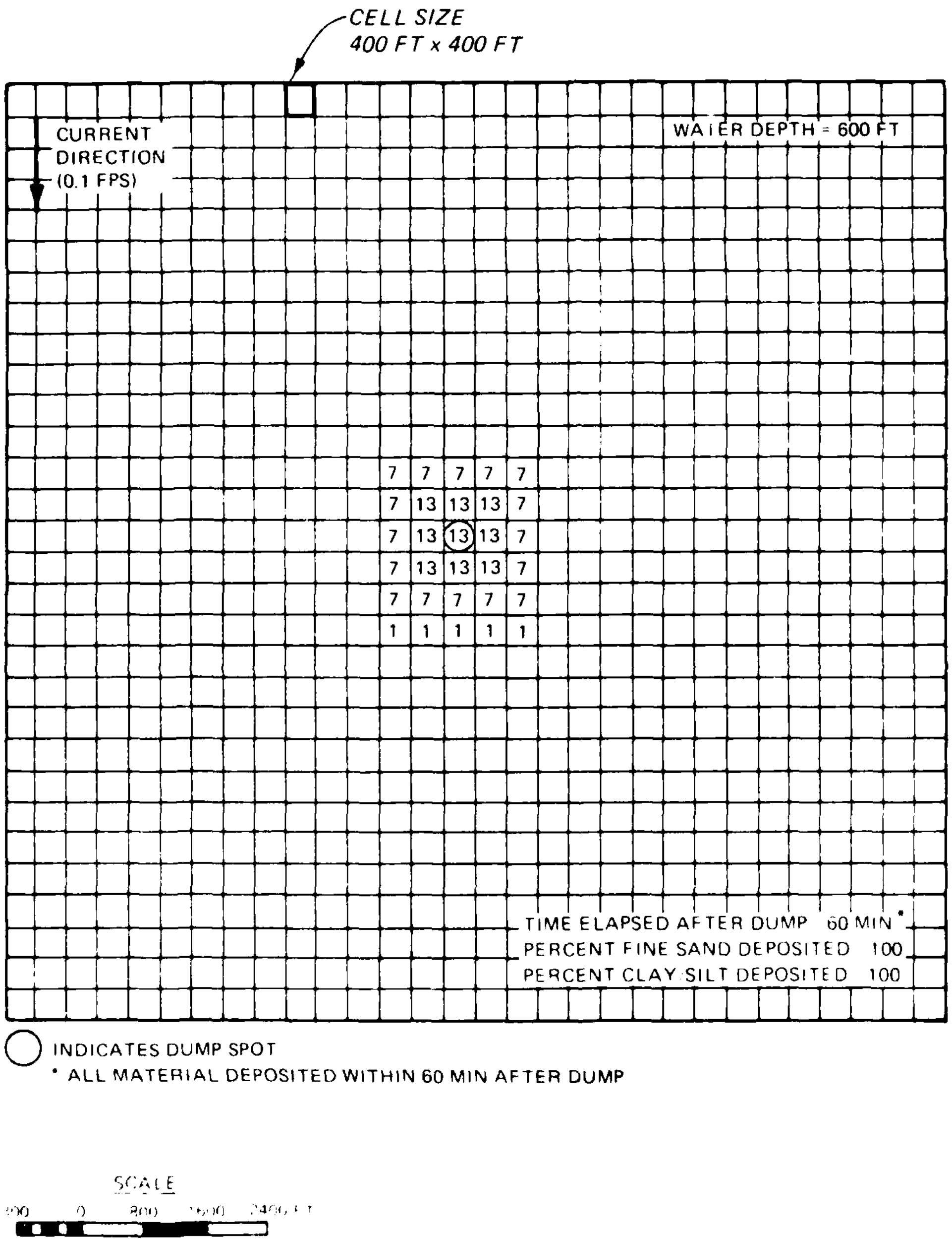



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 8

PLATE 8

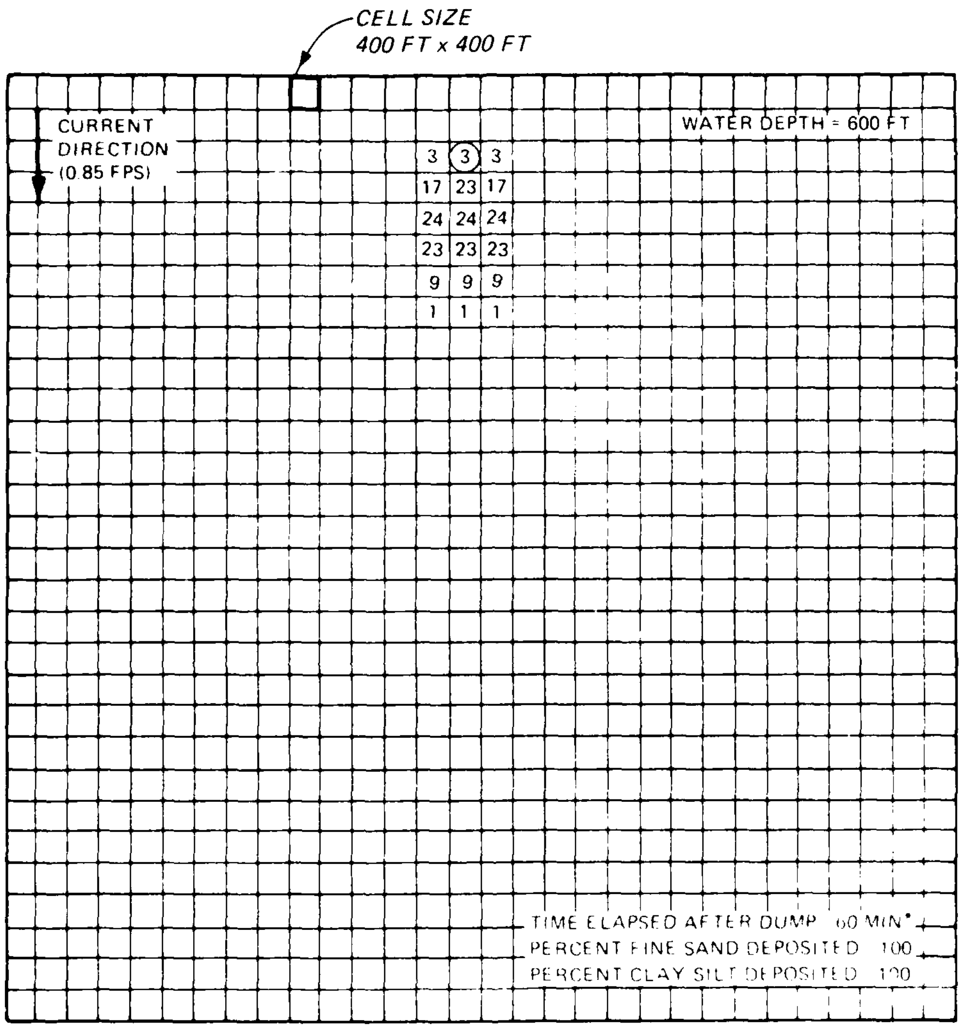



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 9



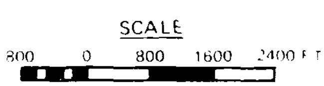

DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 10

PLATE 10

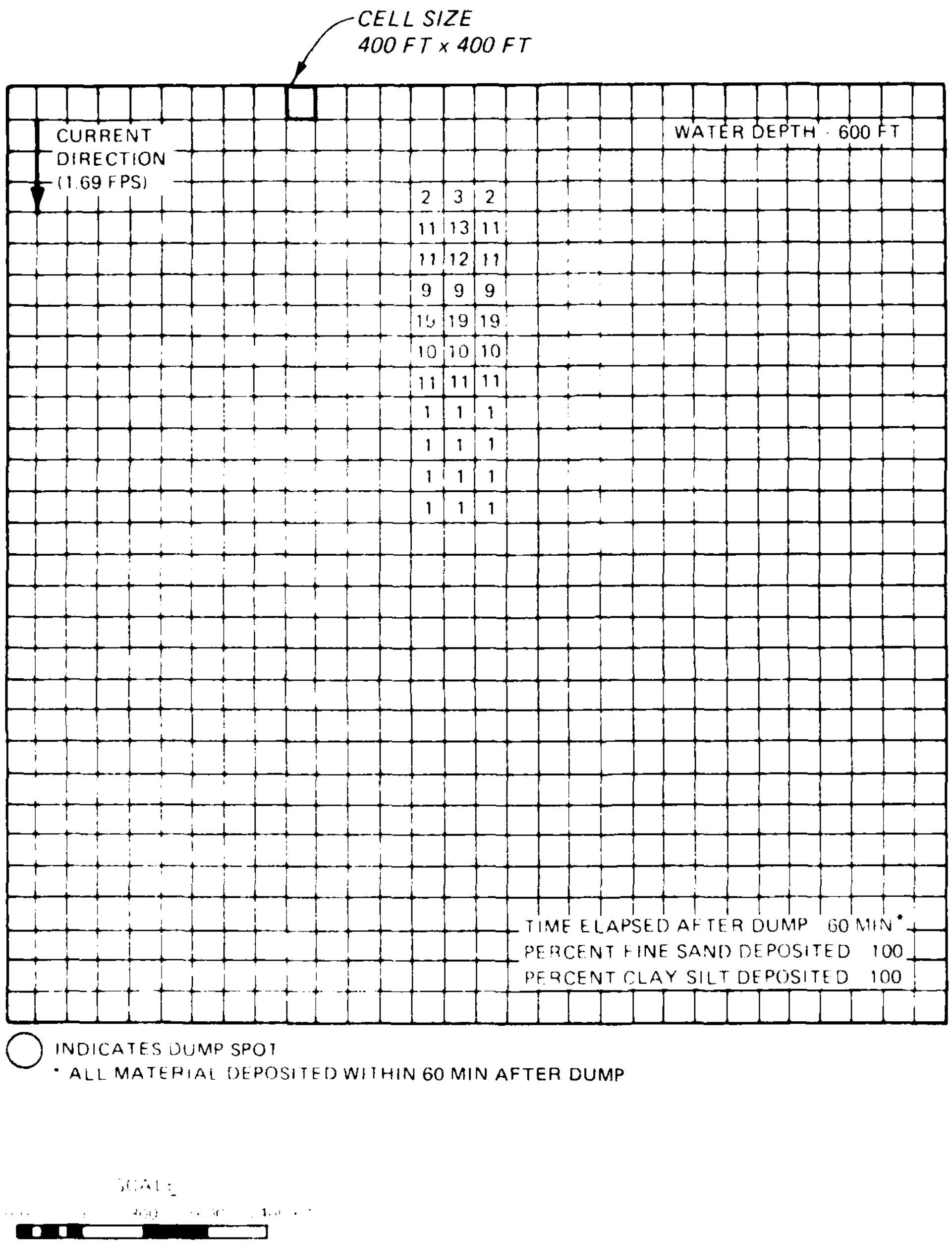



◯ INDICATES DUMP SPOT

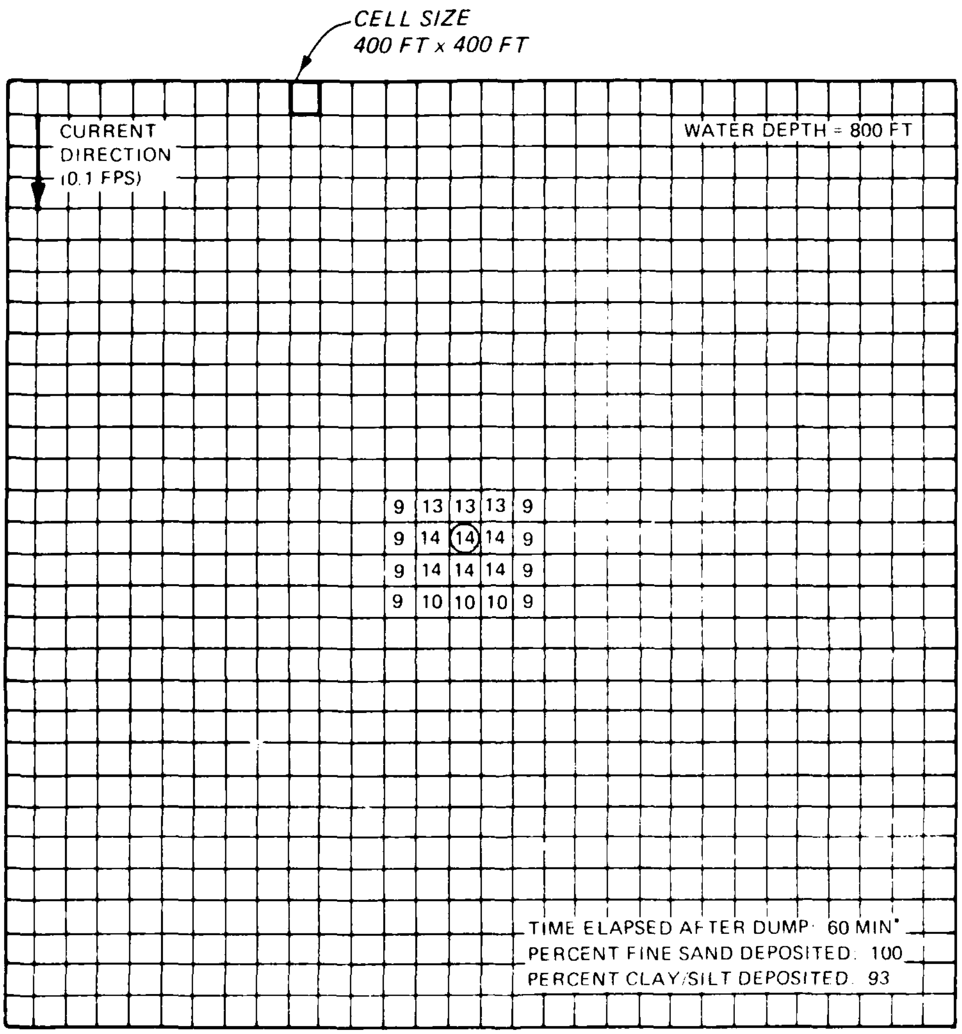
* ALL MATERIAL DEPOSITED WITHIN 60 MIN AFTER DUMP




DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 11




DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 12




◯ INDICATES DUMP SPOT

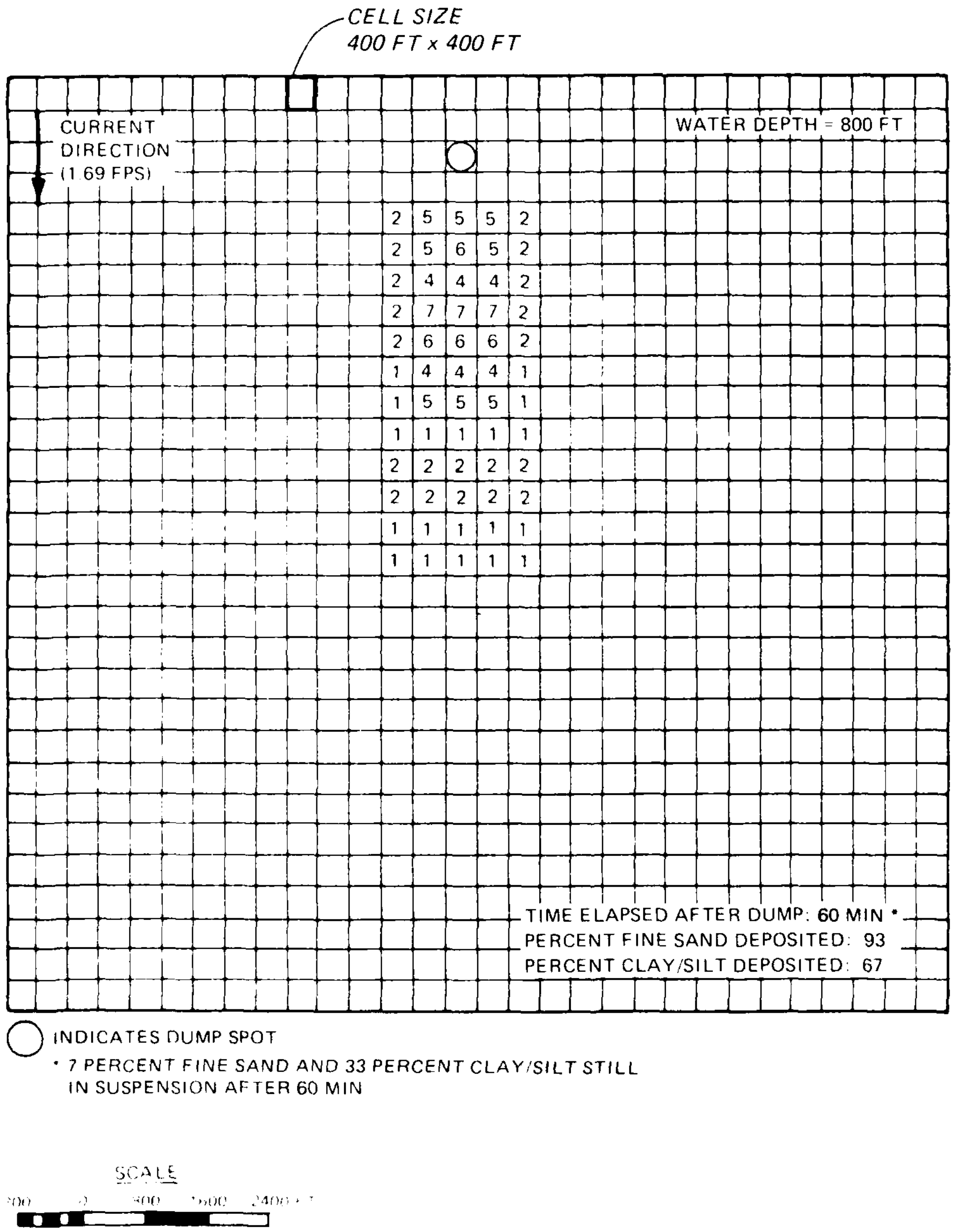
* ALL FINE SAND DEPOSITED WITHIN 30 MIN AFTER DUMP
7 PERCENT CLAY/SILT STILL IN SUSPENSION AFTER 60 MIN

SCALE

800 0 800 1600 2400 FT

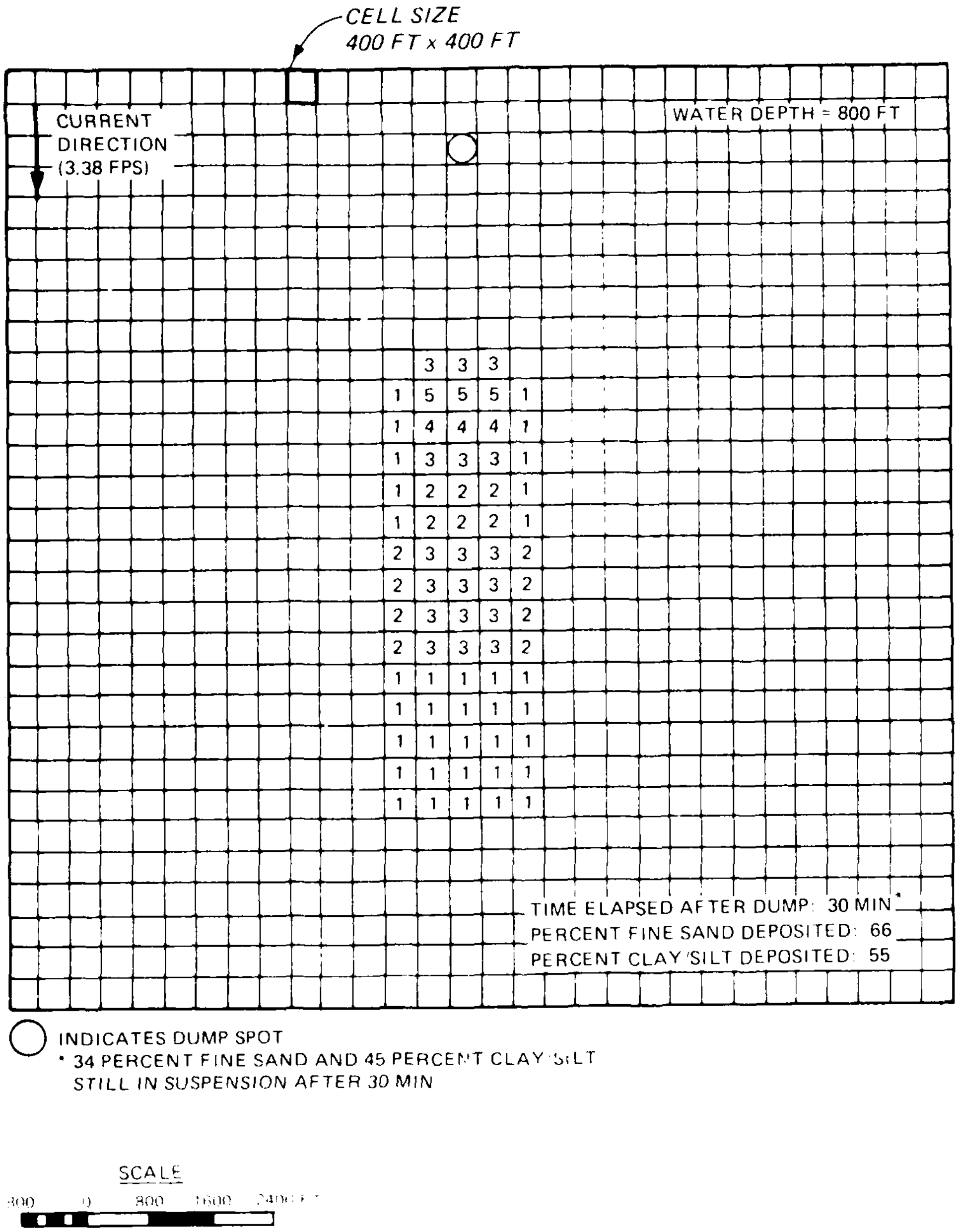
DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 13

PLATE 13

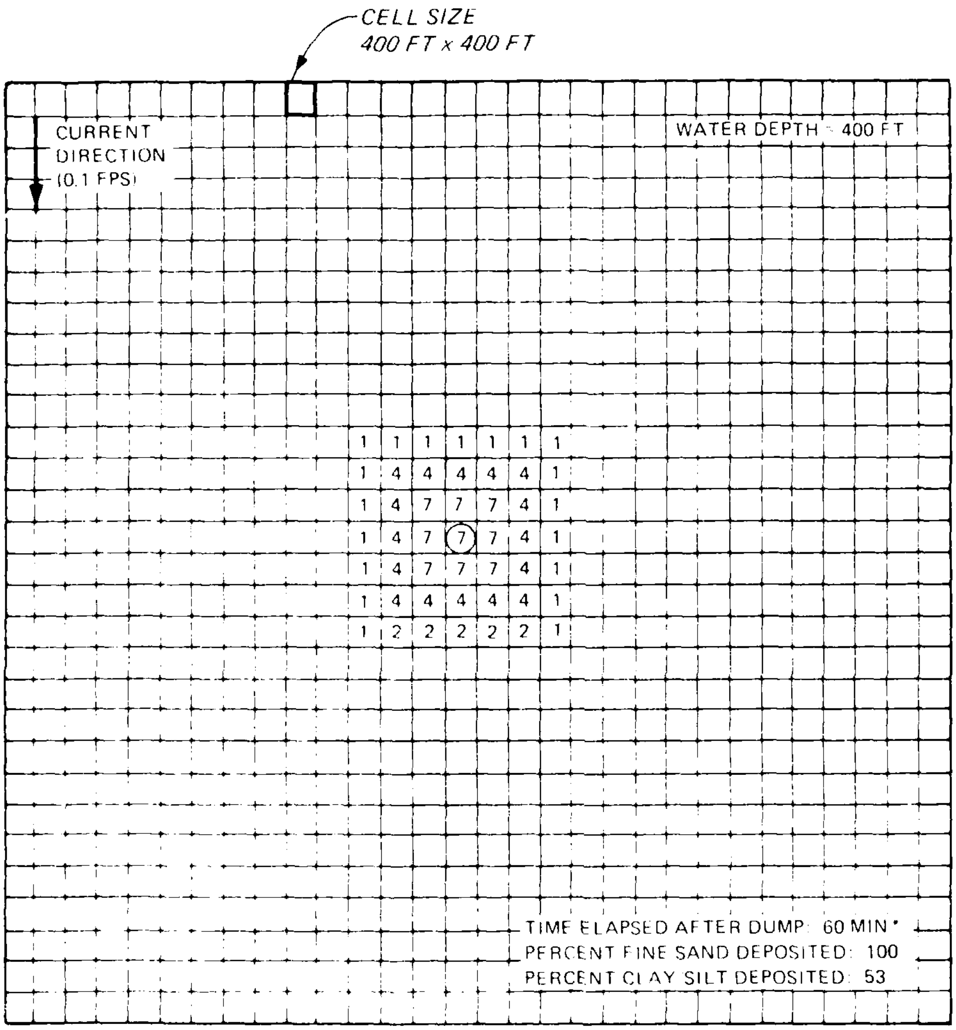



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 14

PLATE 14




DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 15

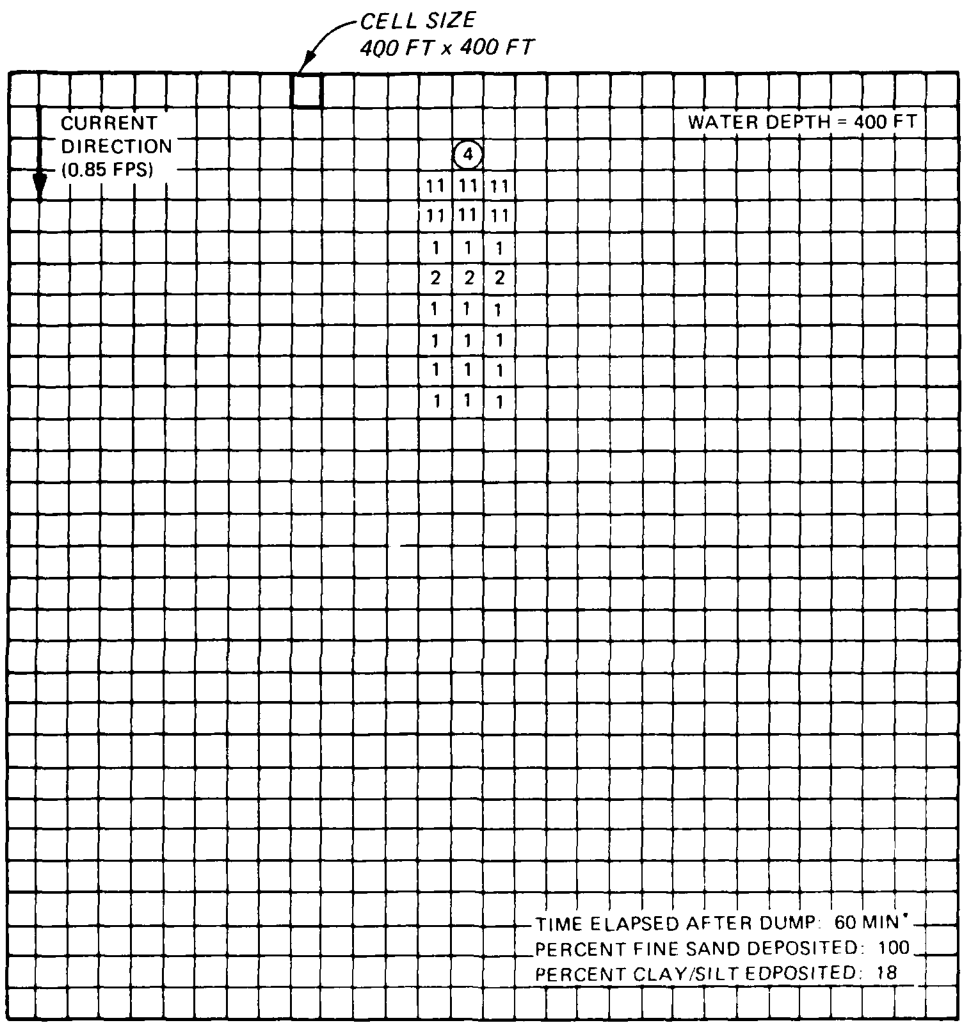



◯ INDICATES DUMP SPOT

* ALL FINE SAND DEPOSITED WITHIN 10 MIN AFTER DUMP
47 PERCENT CLAY SILT STILL IN SUSPENSION AFTER 60 MIN

DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO 16

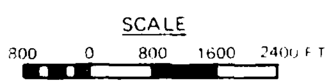
PLATE 16



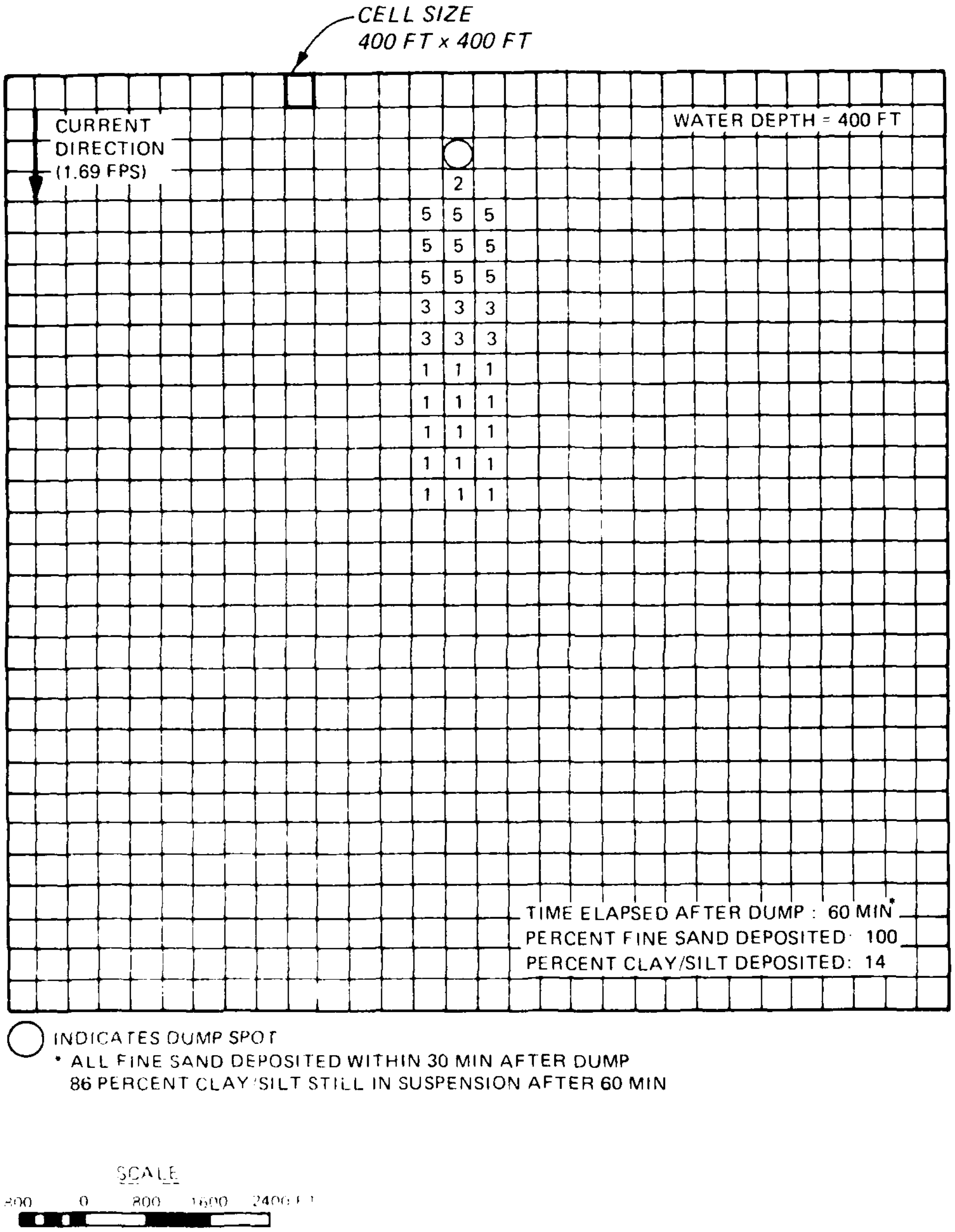

◯ INDICATES DUMP SPOT

* ALL FINE SAND DEPOSITED WITHIN 10 MIN AFTER DUMP

82 PERCENT CLAY/SILT STILL IN SUSPENSION AFTER 60 MIN

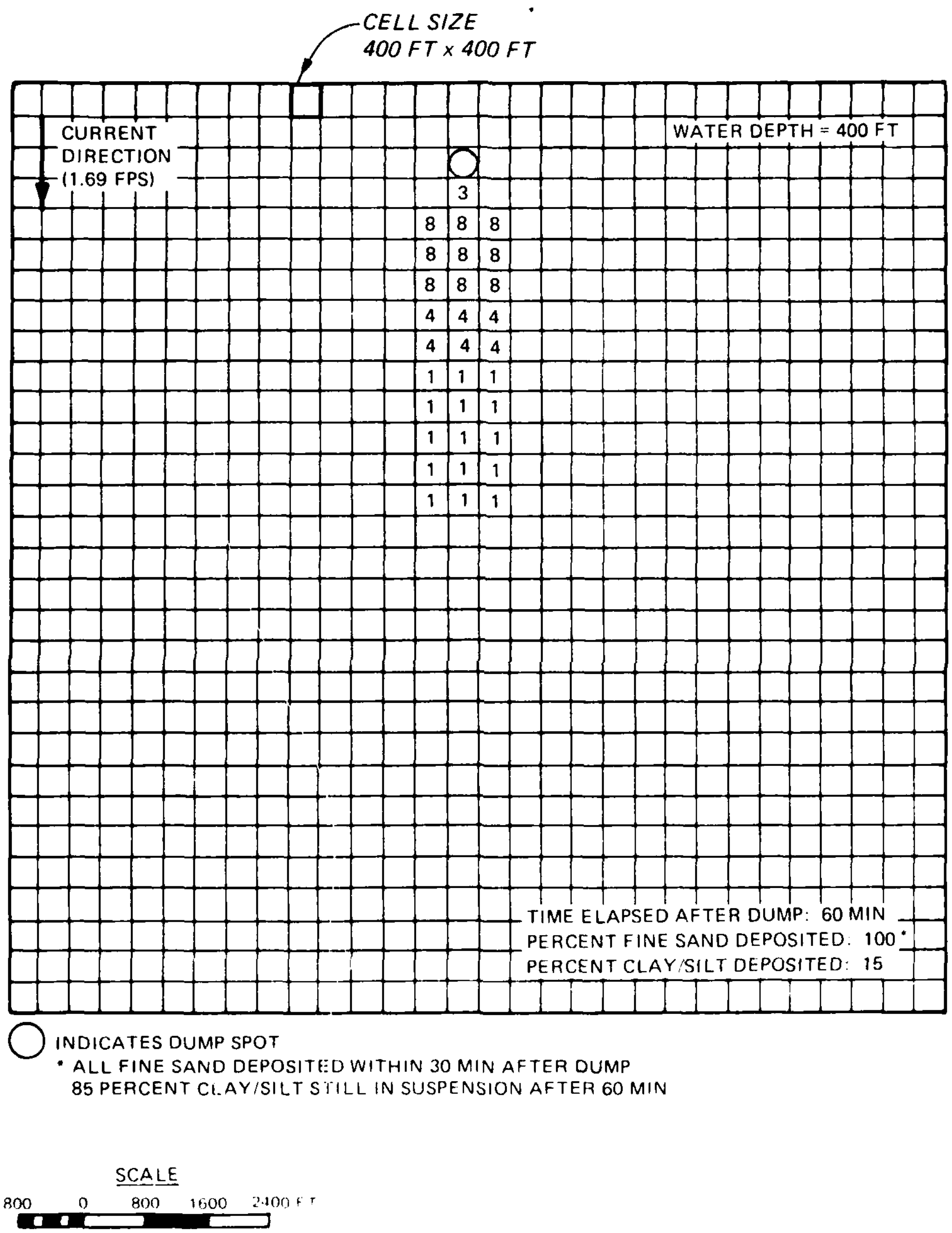



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 17

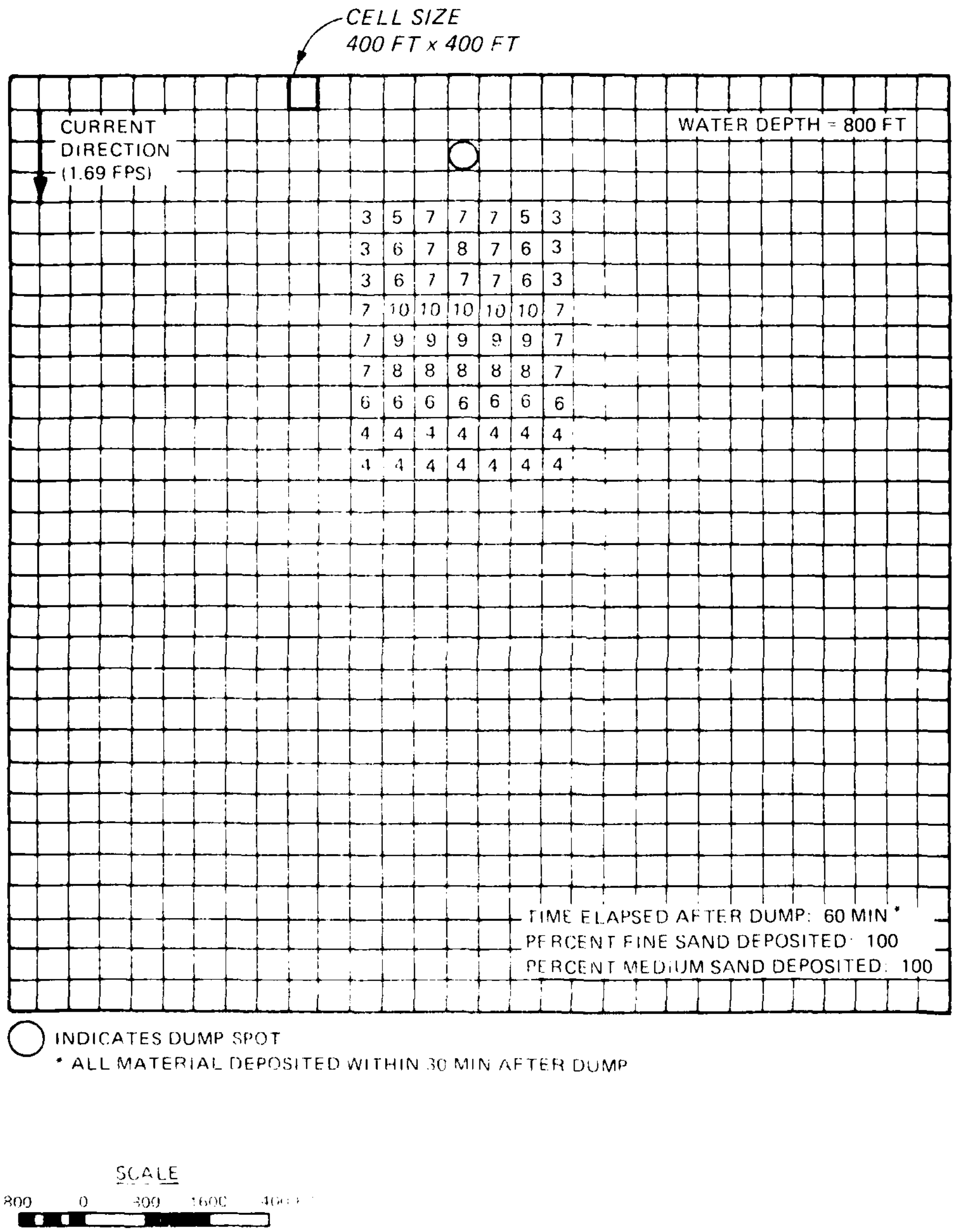



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 18

PLATE 18

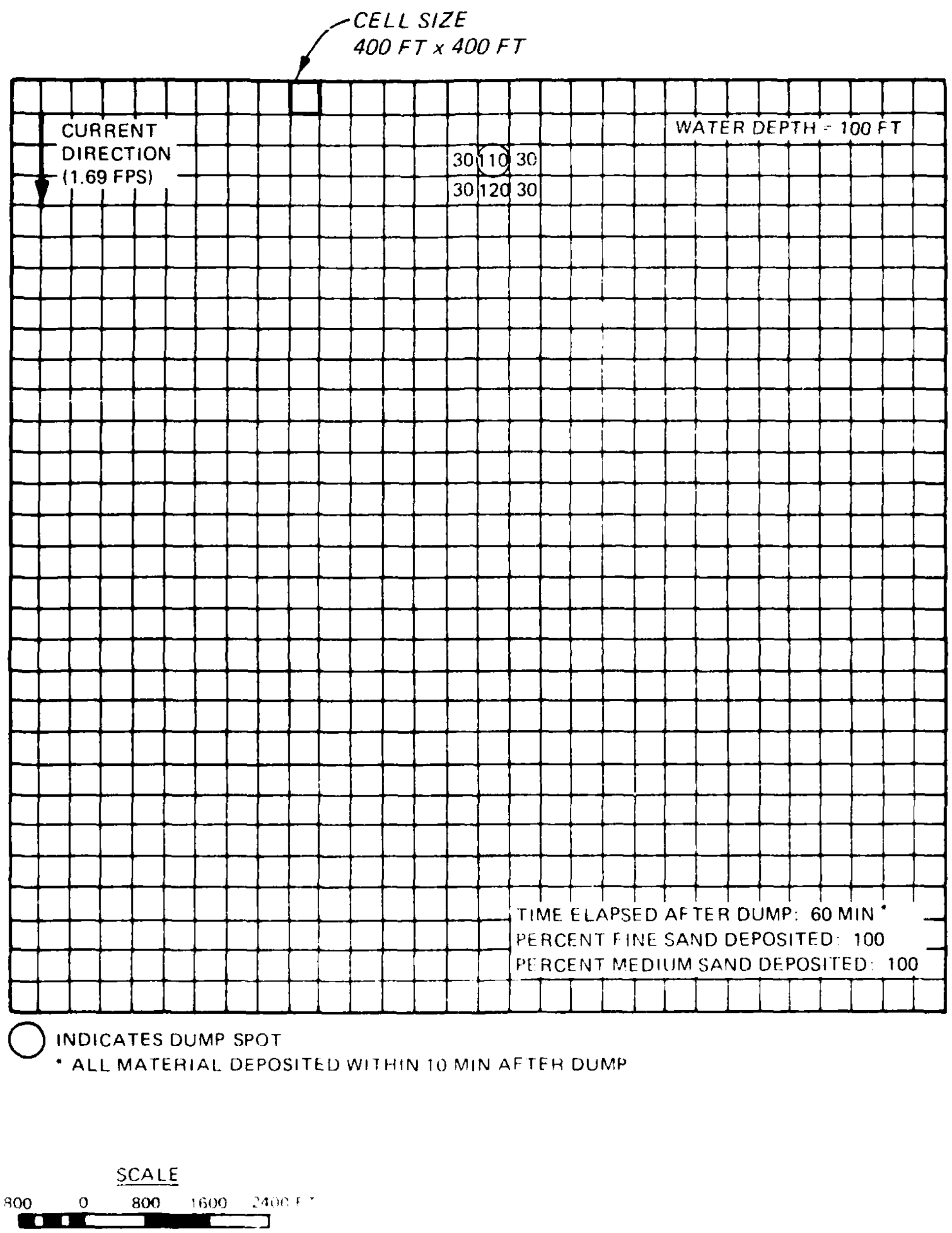



DEPOSITION PATTERN
(IN THOUSANDTHS OF A FOOT)
TEST NO. 19




THICKNESS OF DEPOSIT MAP
(THOUSANDTHS OF A FOOT)
TEST NO. 20

PLATE 20




THICKNESS OF DEPOSIT MAP
(THOUSANDTHS OF A FOOT)
TEST NO. 21

PLATE 21

END

12-86

DTIC